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DESIGN AND ANALYSIS OF INTAKE MANIFOLD USING 3-D CFD ANALYSIS

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ABSTRACT

An efficiently design manifold is pivotal for optimal performance of IC Engine. This paper will discuss about the 3-D stimulation of single cylinder KTM 390 Duke Engine. Both steady and unsteady analysis has been done using ANSYS FLUENT. For this purpose the pressure profile from RICARDO WAVE 1-D code is used.

KEYWORDS: Intake Manifold, Plenum, Restrictor, Runner, Velocity Contours, Ricardo Wave, Ansys Fluent (CFD)

INTRODUCTION

The basic function of the intake manifold is to get the air from the carburettor or throttle body directed into the intake ports. A great intake manifold design can provide substantial performance advantages than a less optimal one. Design goals to be met by the intake manifold-

- Low resistance to airflow
- High air velocity for a given flow rate
- Excellent fuel and air distribution throughout

To achieve desired power and torque, air flow characteristics matter in respect to naturally aspirated engines. Getting air into an engineis the key to making power

As per the rules of SUPRA SAEINDIA and FORMULA STUDENT INDIA competition, there is 20 mm restrictor present between throttle body and engine, to limit engine power capability. To achieve stagnation of air, plenum is used. Runner connects the plenum with engine and is tuned at certain rpm to optimize engine performance. As KTM 390 Duke engine was used for the competition, all analysis was done on three parts – Restrictor, Plenum and Runner.

Specifications of KTM 390 Duke Engine

Single cylinder, twin camshaft, 4 stroke, liquid cooled SI engine

Bore - 89mm

Stroke - 60mm

Compression ratio - 12.88:1

Number of valves - 2 intake + 2 exhaust valves = 4 valves

Intake valve opens - 2° before Top Dead Center (TDC)

Intake valve closes - 44° after Bottom Dead Center (BDC)

Effective Cam Duration (ECD) – 226

PROBLEM DESCRIPTION

Aim of the analysis is as follows:

- To optimize design of convergent- divergent type restrictor
- To optimize plenum shape for having least flow resistance and maximum air flow velocity
- To obtain optimum plenum volume
- To obtain optimum runner diameter

SIMULATION METHODOLOGY

Restrictor

While designing the intake manifold, CFD Analysis is done with ANSYS FLUENT code and system performance is stimulated through use of Ricardo WAVE software.

For the restrictor, we considered the design of convergent-divergent nozzle. Considering packaging within vehicle, length of restrictor is constrained to 115mm. For convergent section, both the end diameters are constrained (43.5mm of throttle body and20mm of the restrictor). For divergent sectionoutlet diameter is 30mm. With all these constraints, parameters left to be optimized are convergent and divergent angles.

With ANSYS FLUENT code, number of iterations of steady flow analysis are carried to optimize these two angles. Inlet pressure is taken equal to 1 atm and outlet pressure has several values ranging from 0.1 to 0.8 atm. For every combination of these pressure boundary conditions, divergent angle is varied and then the graph of mass flow rate vs outlet pressure Figure 1 is plotted.

Plenum

For optimizing plenum shape, the transient CFD analysis is done. Four different plenum shapes were considered, which were vertical cylinder, conical shape, sine wave shaped and spherical shape and results of their analysis were compared to select best plenum shape. Even though aim of analysis was to decide plenum shape only, complete intake system was taken for analysis with appropriate boundary conditions applied at both ends.

Inlet boundary condition was 1 atm pressure and outlet condition was varying pressure. It was applied in the form of pressure profile. This pressure profile was generated through Ricardo WAVE simulation.1-D model of complete engine system with added Intake and Exhaust was built in Ricardo WAVEBUILD software. In this modelling, plenum being a complex geometry, was modelled using RicardoWaveMesher as shown in Figures 3-6. As shown in Figure 7 the whole wave build model is modelled in canvas. Pressure time plot isadded at the end of runner. This time plot generated pressure variation at that location over a complete engine cycle as shown in Figure 8. Such pressure profiles were generated for every plenum shape geometry and transient simulation was done. The velocity vectors of different plenum shapes are shown in Figures 9-11.

Plenum volume was decided through Ricardo WAVE EXPERIMENT. Diameter of spherical plenum was changed in order to vary plenum volume from 1 times to 4 times engine displacement. Its effect on power and torque

curves is observed Figure 15.

Intake Runner

The formula for optimum intake runner length (L) is:

$$L = \frac{EVCD*0.25*V*2}{rpm*RV} - \frac{1}{2}D$$

Where:

EVCD = Effective Valve Closed Duration

RV = Reflective Value

V = Pressure Wave Speed = 1152 ft/s

D = Runner Diameter = 1.7125 inch

EVCD = 720-(ECD)

EVCD = 720-226+20

20° is added to get the effective valve open duration.

EVCD = 514°

According to induction wave tuning theory, intake system was tuned at 5000 RPM, resulting in total runner length of 393mm. For deciding runner diameter, again use of WAVE EXPERIMENT was done. Runner diameter wasvaried from 10mm to 70mm

RESULTS

Table 1

Part	Description
Engine Model	KTM 390
Bore/Stroke	89 mm * 60 mm
Compression Ratio	12.88:1
Cooling System	Water Cooled
Throttle Body	43.5 mm
Intake Runner Length/Diameter	393 mm/40 mm
Intake Restrictor Diameter	19.5 mm
Intake Plenum Volume	746 cc
Restrictor-Convergent/Divergent angle	6 Degree/10.5 Degree
Muffler Type	Modified Laminar flow type

CONCLUSIONS

From the graphs in Figure 1 of mass flow rate plotted for various pressure conditions and various divergent angles, 6 degree divergent angle (hence 10.13 degree convergent angle) gives gradual decrease of mass flow rate with decrease in pressure difference and less flow separation, resulting in less pressure losses.

After transient analysis, velocity vectors in different plenum shapes are compared. In spherical plenum, as depicted in Figures 12-14, central high velocity flow has wider flow area, as less vortices are created. Also, velocity values

are higher for this central flow in spherical plenum when compared with other shapes.

It is observed that engine performance at higher speeds improves with increase in plenum volume (torque peak shifts towards higher engine speeds). However, as design is primarily targeted at lower speed range of 4000 to 6000rpm, volume twice the engine displacement is best solution.

Results from experiment on runner diameter show that, engine performance goes on improving with increasing diameter. However, it is observed that from 40mm diameter onwards, torque curve flattens at lower speeds. Therefore, 40mm is selected as runner diameter, as it is also closer to diameter of stock throttle body (43.5 mm).

This paper has presented the proper procedure of finding the plenum shape by unsteady analysis and also the convergent and divergent angles of restrictor. On changing runner length,maximum torque can shift to the lower RPM.

FUTURE SCOPE

There is future scope to this analysis in Ricardo Wave. Accurate modelling of engine in this software requires number of parameters. Since, most of these parameters are not easily accessible due to Manufacturer Company's privacy policy, there are always approximations while modelling

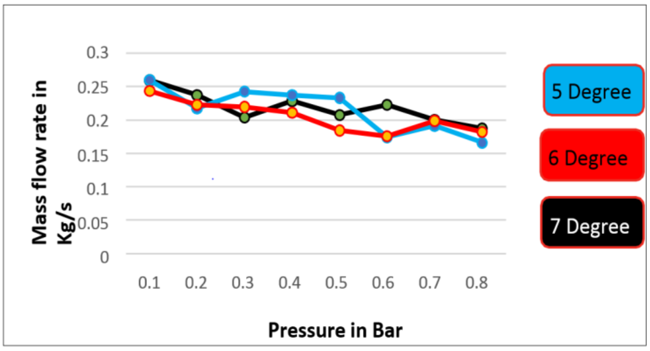


Figure 1: Mass Flow Rate Vs Outlet Pressure in Bar

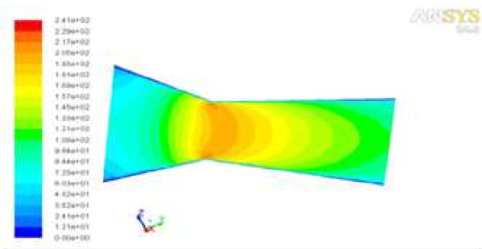


Figure 2: Velocity Contours on Symmetry Plane of Restrictor

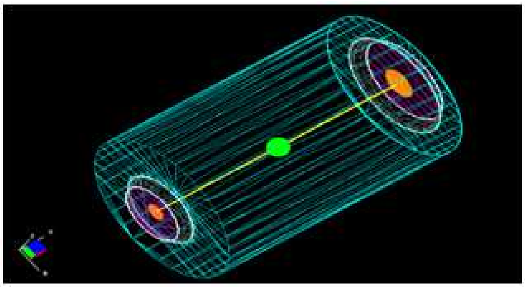


Figure 3: Wave Meshing of Vertical Cylindrical Plenum

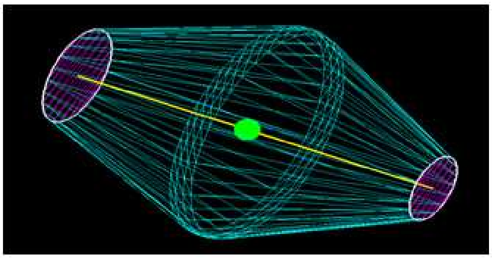


Figure 4: Wave Meshing of Conical Plenum

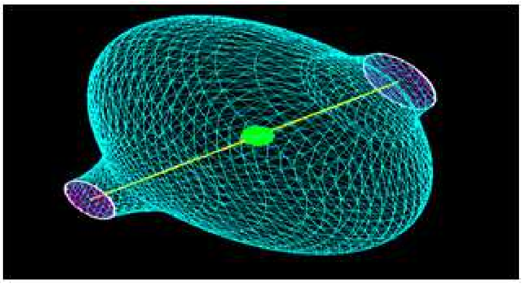


Figure 5: Wave Meshing of Sine Wave Shaped Plenum

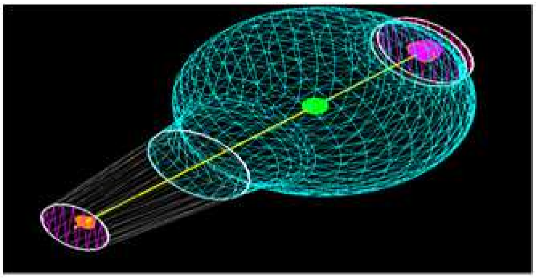


Figure 6: Wave Meshing of Spherical Plenum

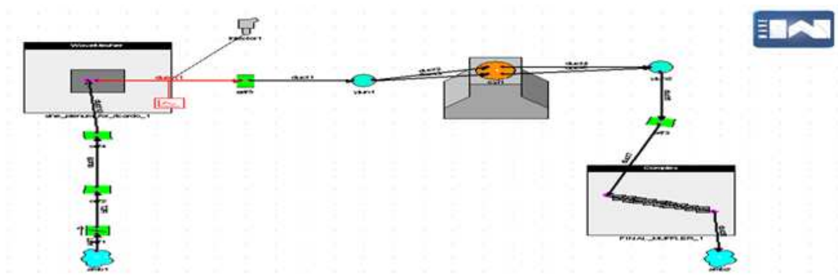


Figure 7: Adding time Plot at the End of Runner in Wavebuild Model

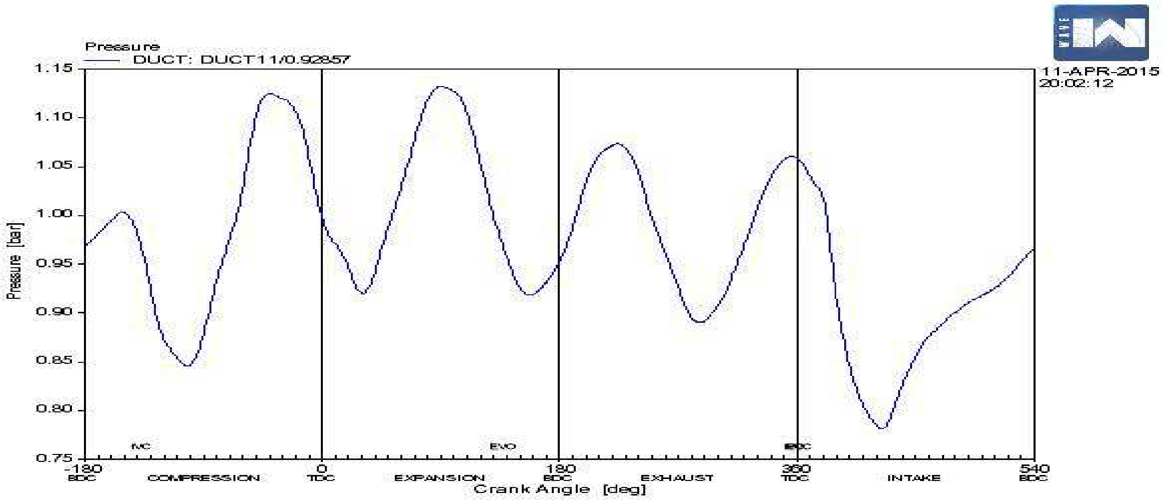


Figure 8: Pressure Variation over a Complete Engine Cycle

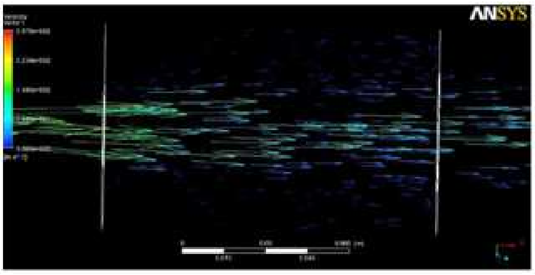
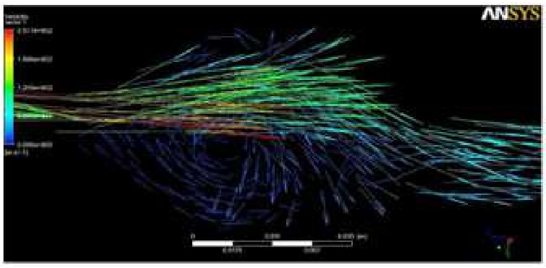


Figure 9: Vertical Cylindrical Plenum- Non Scattered Flow No Flow at the Centre



10: Conical Plenum -Highly Turbulent Flow with Vortex and Formation at the Centre

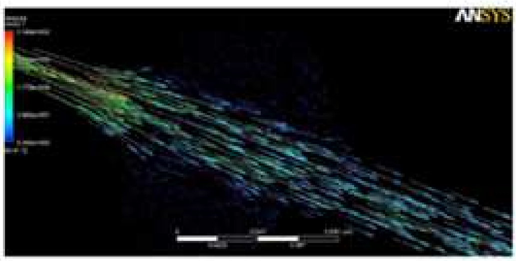


Figure 11: Sine Shaped Plenum-Vortex Present in Very Large Portion of the Plenum

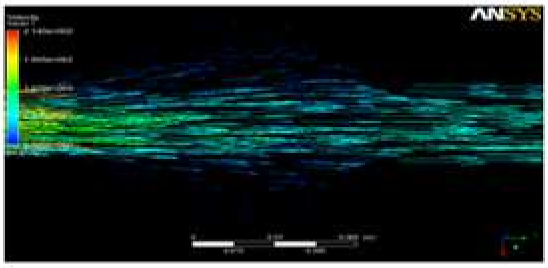


Figure 12: Spherical Plenum Portion of the Plenum

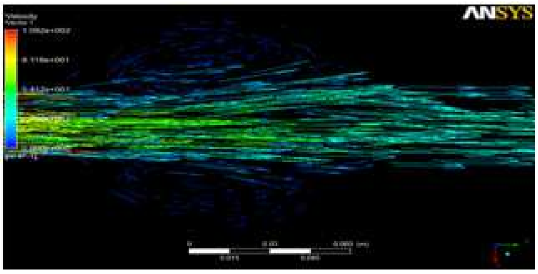


Figure 13: Velocity Vectors for Spherical Plenum: Half Way Suction Stroke

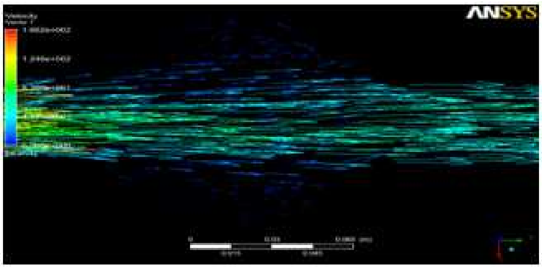


Figure 14: Velocity Vectors for Spherical Plenum: Near the To End of Suction Stroke

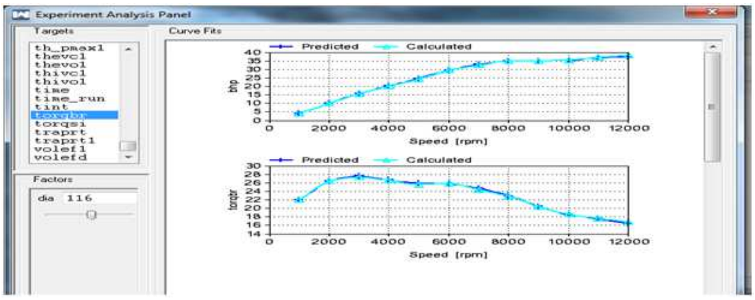


Figure 15: Torque Vs RPM and Bhp Vs RPM Curve

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